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Laser Ignition of Propellants in Closed Chambers

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13. ABSTRACT *(Maximum 200 words)*

Preliminary experiments have been performed in the application of laser ignition to solid and liquid propellants in closed chambers. The effect of confinement on ignitability and the ignition of a range of energetic materials are demonstrated.

14. SUBJECT TERMS

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1. INTRODUCTION

The application of laser ignition to gun propulsion systems is being pursued for many potential advantages. These advantages have been discussed in detail elsewhere (Barrows et al. 1991). Laser ignition may hold solutions to the difficulty of achieving effective ignition of a two-piece cartridge for the Advanced Tank Cannon System (ATACS) or the Modular Artillery Charge System (MACS) for artillery. Laser ignition has also received increasing attention because of its potential to achieve multi-point ignition, simultaneously or in a programmed time sequence. Based on numerical analyses (Williams and Chang 1991), there are indications that ignition in a programmed sequence along the charge length may achieve the goal of high muzzle velocity without the appearance of pressure waves. In addition, the use of low vulnerability propellants (LOVA) has become a major trend in gun design. However, the difficult-to-ignite characteristics of these propellants make it difficult to obtain effective ignition with a conventional igniter system. Furthermore, the performance of advanced charges is sometimes less reproducible and is more sensitive to temperature change than conventional ammunition. All of these problems demand a strong consideration of alternate ignition systems, such as laser ignition.

Although the concept of using laser pulses to ignite propellant is not new, the technology must be advanced before the concept becomes practical. The major difficulty is to ignite a propelling charge with an ignition delay acceptable to gun users. To meet this requirement, various laser beam parameters can be explored, such as power, energy, flux, and wavelength. While direct ignition of the propellants is desirable, it is difficult to achieve and remains a long-term goal of the program. In indirect ignition, the laser ignites an energetic material of higher ignitability that is embedded in the propellant bed. The combustion products then ignite the surrounding propellant.

The ready ignition of several propellants in the open air has been earlier demonstrated in our lab and elsewhere. In the present work, studies have been begun to study ignition in confined vessels, which are a step closer to ignition in a gun chamber. This report discusses primarily the ignition of small samples of solid and liquid propellant (LP) that are confined by a chamber with limited ullage. The ignition characteristics are observed and guidelines are set for future work.

2. EXPERIMENTAL

The chamber used in most of these studies is shown in cross section in Figure 1. It was machined out of 316 stainless steel and has a chamber capacity of 0.1 cm^3. While it was originally designed with a sapphire window, the use of the mylar as a combination window and blowout disk has proven to be advantageous for bench top survey studies. The transmission of the mylar is much less than typical windows or fiber optics, but that creates no difficulty for these studies. The chamber is held together by six bolts. The back wall is formed by the pressure gauge, as shown. No protective grease was used on the gauge because of the very limited volume. There were also concerns that the grease would introduce significant nonreproducible effects on the volume and heat transfer to the walls. Thus all pressure traces have the characteristic negative shift due to heating of the pressure transducer; this shift is only cosmetic for these studies.

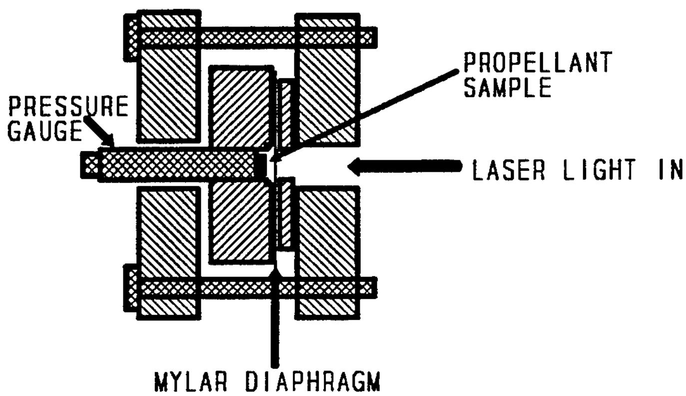

Figure 1. Schematic diagram of laser ignition chamber.

The laser used in these studies was a neodymium glass laser operating at 1.054-μm wavelength with pulse length variable from 100 μs to 10 ms and variable energy. For these studies, the light was focused to a 0.125-in-diameter spot with a 2-in focal length lens. Except as noted, the mylar was 0.020 in thick (four layers of 0.005 in each). For some of the studies, a second expansion chamber was created by adding a spacer after the diaphragm with a second diaphragm. In most cases, the volume of this second chamber was 0.05 cm^3. This arrangement allowed the study of how completely the propellant was ignited, and whether sudden, but incomplete, depressurization would extinguish it. The results obtained from this configuration will also be important in the study of laser ignition where the irradiated material could be placed in a confined volume to enhance ignition; after ignition, the confinement would rupture and the following processes take place in a depressurized environment.

3. OBSERVATIONS: SINGLE CHAMBER

In most of the observations described here, a graphite coating was required on the propellant surface in order to have sufficient energy absorbed to ignite the sample. Whether the problem is reflection or transmission of the light has not yet been determined definitely, except in obvious cases such as M9 where it is possible to burn objects behind the propellant sample with the transmitted light.

3.1 Black Powder (BP). One material not needing a coating to enhance absorption was BP. This material was tested as a bench mark because of its ease of ignition and rapid flamespread. A typical pressure trace is shown in Figure 2. For this record, as much sample was put into the volume as possible without grains damaging the diaphragm, which resulted in an estimated 60–70% loading density. A 10-ms laser pulse was used. The time zero in the figure is the start of the laser pulse. Approximately 1.5 J of energy was incident on the sample surface before ignition, which occurred at about 4.5 ms; this short time is adequate for most gun system minimum requirements. Note that the pressure gauge does not go negative before the event due to the opacity of the sample. As expected in the event, the ignition was clean and unambiguous. BP is unique among the materials tested in that the confinement and pressurization appear to have little effect on the ignition and flamespread rates.

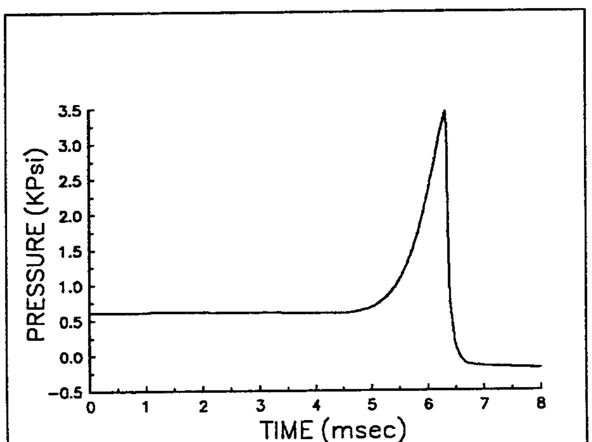

Figure 2. BP pressure response to laser ignition in small cell.

3.2 M30 Propellant. Figure 3 shows the typical behavior of a slice of M30 propellant grain when tested in the same manner. Note that the pressure gauge is heated by the laser prior to the ignition. Since this sample required a graphite coating for prompt ignition, the light probably was going either around the propellant or through the perforations in the grain. Approximately 5 J of light energy was incident on the propellant surface before ignition took place. As with the BP, this value was well above any threshold and merely a convenient value to ensure ignition. A comparison of Figure 3 with Figure 2 shows that the pressure rise was noticeably slower for the M30 grain, indicating a slower ignition and flamespread process.

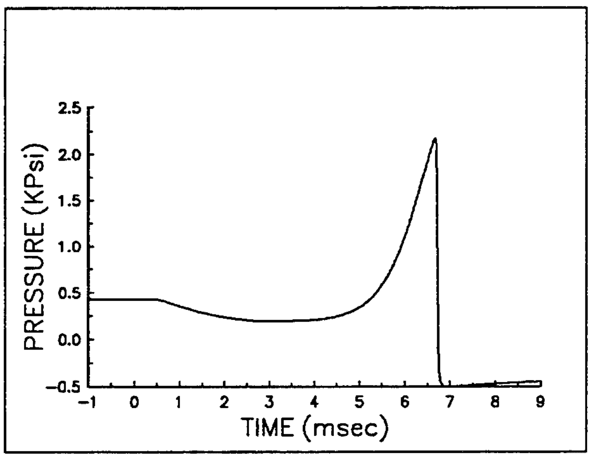

Figure 3. M30 laser ignition.

3.3 M43 Propellant. Several LOVA propellants were studied briefly. The response of one of these, M43, is shown in Figure 4. Approximately 8.5 J of laser energy were incident on the solid surface during 10 ms. As can be seen in the plot, the laser raised the pressure sufficiently that full ignition of the propellant took place shortly thereafter. The pressure rise was much slower in comparison with BP and M30 propellant in the previous Figures. This result was expected because of the difficulty of igniting the LOVA propellants.

In many of these experiments, careful measurements were made of the mass lost by the propellant sample during the event by weighing the samples before and after the event. In this case, the original sample was 90.0 mg before irradiation and 86.6 mg after the event shown. The mass lost by a similar piece of material under the same laser conditions, but without confinement and ignition, showed a mass loss of approximately 0.1 mg, which is at our level of measurement uncertainty. The amount of mass lost

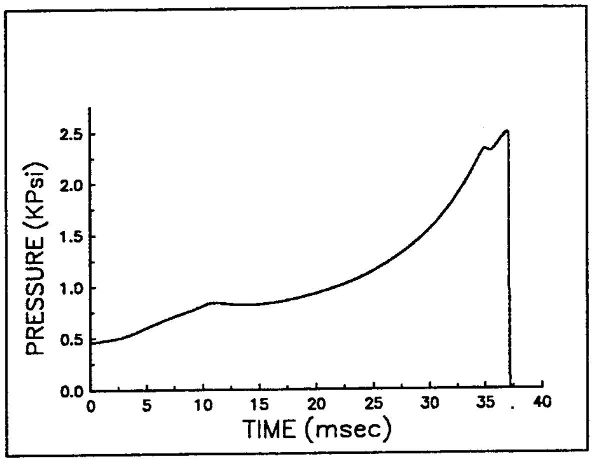

Figure 4. M43 ignition on third pulse.

when an M43 propellant sample was ignited for these brief times varied from 2 to 9 mg and appeared to be independent of the original mass.

3.4 LP1846. Although the liquid propellants are also quite transparent at 1.054 μm, most experiments were done without adding graphite. It also ignited vigorously and promptly with the laser source. As can be seen in Figure 5, ignition delay was about 5.5 ms for this typical example. The LP is most obviously different from the solids in that it blew itself out of the chamber almost completely. In the single diaphragm experiments, it behaved much like the M43 in the sense of needing good confinement and pressurization during the laser pulse in order to achieve ignition.

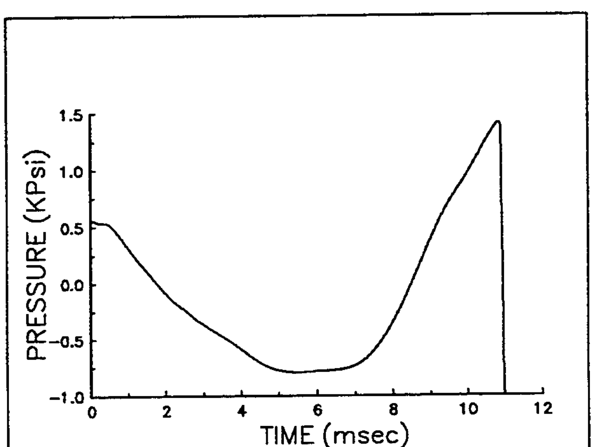

Figure 5. Laser ignition of LP1846.

4. OBSERVATIONS: DOUBLE CHAMBER

As mentioned, it was decided to provide the propellants a little more burning space, in part to establish that they were really vigorously burning and to increase the measured mass loss. Three examples of typical behavior are presented here.

4.1 Solid Propellants. The energy to the surface for the M30 event shown in Figure 6 was less than 3 J before the apparent ignition time. As can be seen, the second diaphragm broke at a lower pressure than the first. The pressure behavior before the burst of the first diaphragm is quite similar to that recorded in the single chamber ignition, such as shown in Figure 3. In the case of Figure 6, the sample lost 12.1 mg, or 9.5% of the total mass. A similar record for an M43 sample is shown in Figure 7. Note that the ignition in this case is more prompt and unambiguous than in the sample shown for the single chamber ignition of the same material; this behavior is due to the use of a previously burned and extinguished propellant sample. The pressure record again shows good sustained ignition. The sample from this and similar tests show the smooth, glassy surface and enlarged perforations that are indicative of flamespread over the entire surface.

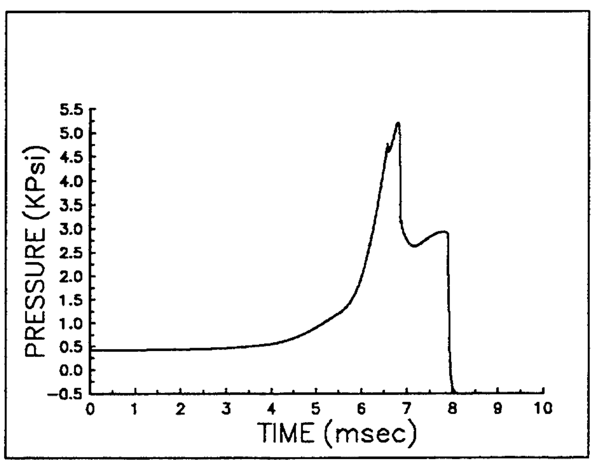

Figure 6. M30 laser ignition in dual chamber fixture.

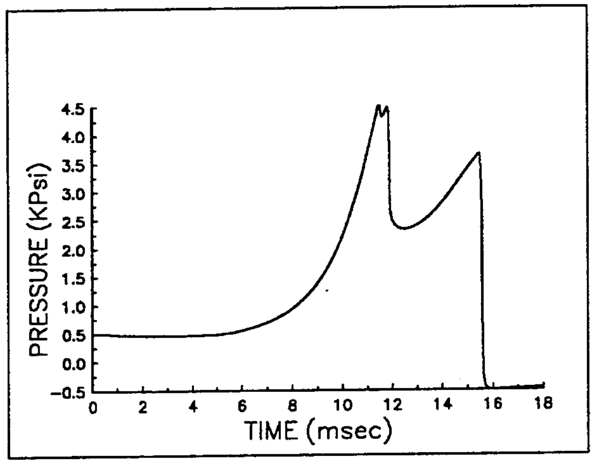

Figure 7. Ignition of previously ignited and quenched M43 in dual chamber.

4.2 LP. The behavior of LP1846 in the double chamber studies was significantly different from the solid propellants. As can be seen in Figure 8, the second peak is very sharply rising and goes higher in pressure before the diaphragm can burst and relieve the pressure. In addition, inspection of the diaphragms after the event show similar behavior for the first diaphragm for solids and liquids but differences in the second. In the case of solid propellants and the first diaphragm of the LPs, the two burst patterns are typical of a stretch-and-break event. The second LP disks show a larger, smoother hole that probably has experienced a much greater flow of high-temperature materials (gas or liquid). The main difference here is probably due to the in-depth heating, reaction, and ignition of the LPs (i.e., when they ignite, the whole volume is involved rather than just the surface). The pressure traces are shown in Figures 8 and 9 for two levels of irradiation. The observed behavior with similar shapes but shorter times with greater energy is classical laser ignition behavior.

Some brief effort was made to develop a second chamber with a small vent that might simulate an igniter component for LPs. The goal is to keep the pressure elevated to continue combustion while venting hot gases and reactive chemical species to use for ignition. In Figure 10, an example is shown for LP1846 where the venting of pressure sustained the event for about 10 ms beyond what would have occurred with closed chamber. Similar tests were done with solid propellants. In some of these cases, significantly longer burn times were achieved.

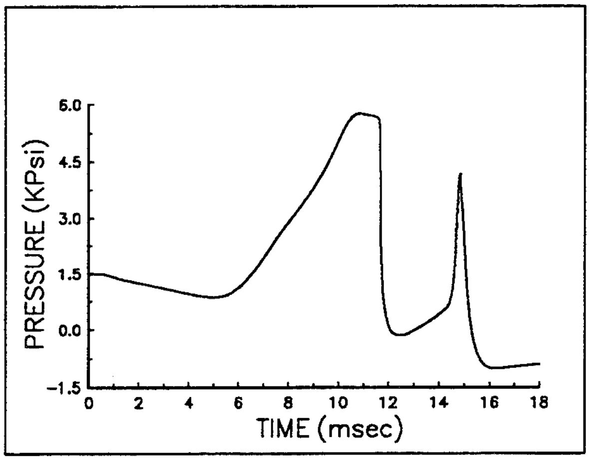

Figure 8. LP1846 ignition with 6.5J of laser energy in the dual chamber vessel.

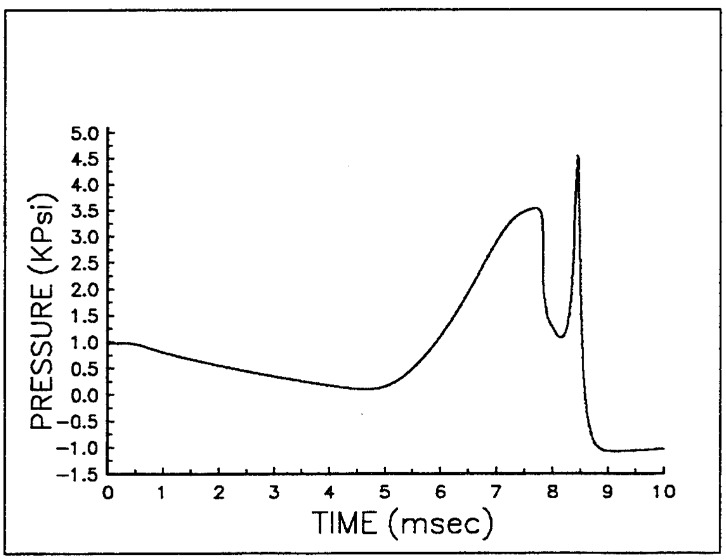

Figure 9. LP1846 ignition with 8.5J of laser energy.

5. OBSERVATIONS: GUN SIMULATOR

Preliminary studies have been made of laser ignition in a 25-mm gun chamber simulator designed to scale the behavior of larger guns (see Figure 11). While both BP-assisted ignition and direct laser ignition were explored briefly, the efficient coupling of the laser energy into the propellant has not been adequately demonstrated in these brief studies. As expected, ignition using BP was readily achieved. An example

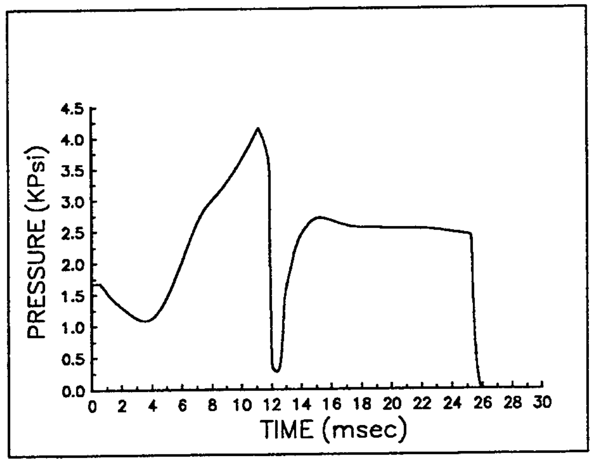

Figure 10. Ignition of LP1846 with vented second chamber.

of an event using a small amount of BP attached to the surface of a JA2 grain to assist ignition of the grain is shown in Figure 12. In this test, the grain was placed near the window at the breech end of the simulator with the rest of the chamber filled with inert grains. In the figure, the first and second pressure rises are due to the ignition of the BP and the JA2 grain, respectively. Inspection of the grain after the event, which was terminated by the diaphragm burst and grain extinguishment, again showed good flamespread to the extent that the perforations were enlarged and joined at some parts of the grain. While direct ignition of JA2 was achieved in this simulator, it has not been done with reasonable delay or good reproducibility. Obvious difficulties to be addressed for direct ignition include heat loss to the window if the grain is tightly packed against the window and efficiently coupling of the energy into the propellant.

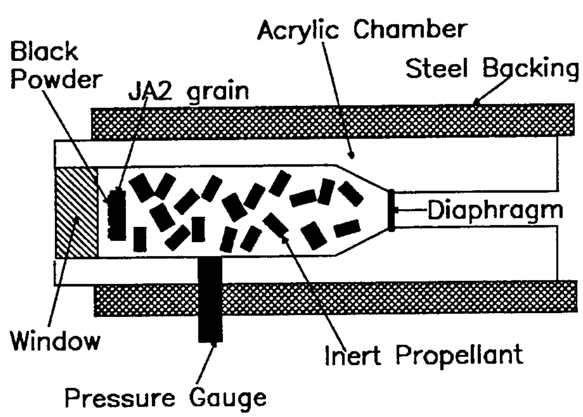

Figure 11. Schematic diagram of 25-mm gun chamber simulator.

6. SUMMARY AND CONCLUSIONS

A variety of propellants have been shown to be readily ignitable by laser light at a wavelength that is producible in compact, efficient package size. Ignition delay times vary substantially around the typical values shown here; the major uncontrolled variable is presently thought to be the coupling of the energy into the propellant.

7. FUTURE WORK

As discussed in the preceding descriptions, future work will include efforts to couple light more efficiently into the propellants, wavelength studies, application of fiber optics for multi-point ignition of a propelling charge, and extensive studies with gun simulators.

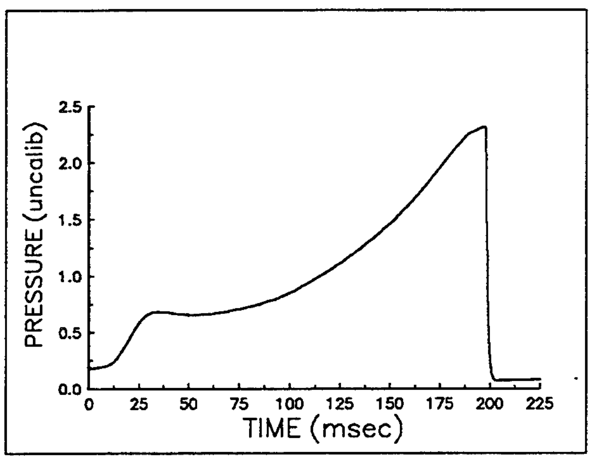

Figure 12. Pressure trace from ignition of JA2 with BP assisted laser ignition in 25-mm simulator.

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